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EXPERIMENTAL INVESTIGATION OF A CIRCULATION CONTROL AILERON

by

Steven W. Prince

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AVIATION AND SURFACE EFFECTS DEPARTMENT

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Aileron
Circulation Control
Roll Control

0.8 million per ft (2.62 million per m)

sq ft sq m

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A Circulation Control (CC) aileron was tested on a semispan wing-fuselage model at a dynamic pressure equal to 20 lb/ft^2 (957 N/m^2) and a Reynolds number of 0.8×10^6/ft (2.62×10^6/m). Three different trailing edge geometries were used on CC ailerons of 10 and 20 percent of the half span. Blowing was controlled to produce jet momentum coefficients from 0.0017 to 0.0124. Rolling moment coefficients as high as 0.035 were recorded for the 20-percent CC aileron for angles of attack between 0 and 12 deg. The

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CC aileron was at least three times as effective as a pure reaction jet for the same amount of bleed air. Adverse yaw was large, on the order of one-half of the rolling moment.

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NOTATION

A	Area of slot
AR	Aspect ratio
b	Wing span
C_ℓ	Rolling moment coefficient
C_n	Yawing moment coefficient
C_μ	Momentum coefficient based on wing area
$C_{\mu A}$	Momentum coefficient based on aileron section area
$\dot{m}$	Mass flow
P_d	Wing plenum total pressure, psig
P_∞	Free-stream static pressure, psig
q	Free-stream dynamic pressure, lb/ft^2
R	Universal gas constant
S	Wing reference area, ft^2
s	1715 ft^2/sec^2 R
T_d	Wing plenum total temperature
V_j	Jet velocity
α	Angle of attack (deg)
γ	Ratio of specific heats

ABSTRACT

A Circulation Control (CC) aileron was tested on a semispan wing-fuselage model at a dynamic pressure equal to 20 lb/ft^2 (957 N/m^2) and a Reynolds number of 0.8×10^6/ft (2.62×10^6/m). Three different trailing edge geometries were used on CC ailerons of 10 and 20 percent of the half span. Blowing was controlled to produce jet momentum coefficients from 0.0017 to 0.0124. Rolling moment coefficients as high as 0.035 were recorded for the 20-percent CC aileron for angles of attack between 0 and 12 deg. The CC aileron was at least three times as effective as a pure reaction jet for the same amount of bleed air. Adverse yaw was large, on the order of one-half of the rolling moment.

ADMINISTRATIVE INFORMATION

This study was authorized and funded by the Naval Air Systems Command (NAVAIR) 320D under Program Element 62241N and Task Area WF 41 421 000. The work was completed in FY 79 at the David W. Taylor Naval Ship Research and Development Center (DTNSRDC) under Work Unit 1-1600-079.

INTRODUCTION

Insufficient roll control power is a problem with many vertical/short takeoff and landing (V/STOL) aircraft at transition speeds. A large amount of roll control power is required to trim out a lift-jet induced rolling moment due to sideslip. Rolling moment coefficient can approach 0.3 in a 30-deg sideslip.[1] A Circulation Control (CC) aileron is a potential method of providing adequate roll control power at transition speeds without excessive bleed air requirements.

A CC aileron is a powered roll control device in the same location on the wing as the aileron. The CC aileron uses tangential blowing over a round trailing edge to produce increased section lift coefficients. The jet blown over the round trailing edge stays attached by the Coanda principle. It moves the trailing edge stagnation point to the underside, increasing circulation.[2] Roll control is achieved by blowing the CC aileron on one wing to raise the wing. The trailing edge can be retracted or faired in by various means for high-speed flight.

MODEL DESCRIPTION

The model is a semispan wing fuselage mounted on a circular groundboard. The principal dimensions of the model are shown in Figure 1. The Circulation Control airfoil is a 14-percent thick supercritical wing with a circulation control round trailing edge (Figure 2). The wing had an aspect ratio of 4.0. Blowing air was supplied through a wing plenum. The CC aileron section was made by closing the slot over the inboard section of the wing with gasket material so only the outboard section was blown. The gasket material extended approximately 0.25 in. (0.64 cm) out of the slot to insure separation of the flow over the rounded trailing edge. Intermittent flow attachment over the round unblown section was suspected to have caused the considerable scatter found in the previous data. Two CC aileron spans were investigated; one of 20-percent half span with a slot extending 4.94 in. (13.56 cm) from the tip and the other of 10-percent half span with the slot extending 2.47 in. (6.27 cm). Three different trailing edge geometries were investigated; see Figure 3. A fence was used to separate the blown CC aileron section from the rest of the wing as shown in Figure 4.

The wing-fuselage model was mounted in the wind tunnel test section such that only the wing was attached to the balance frame. The wooden fuselage was mounted to the groundboard and was independent of the balance frame with a small gap existing between the wing root and the fuselage body. The forces and moments measured by the balance frame were essentially wing-alone data in the presence of a body. A large fence was installed around the wing root area very close to the fuselage. The fence is shown in Figure 2, and its position is noted in Figure 1.

The circular ground board is 8 ft (2.33 m) in diameter and serves as a reflection plane for the half model. The groundboard is constructed from 0.5 in. (1.2 cm) plywood and is mounted to the test section floor on 2.5 in. (6.35 cm) wooden spacers, leaving a gap between the groundboard and the tunnel floor for boundary layer bleed. The groundboard is shown in Figure 1 and additional details are shown in Figure 5.

WIND TUNNEL EXPERIMENT

The investigation was conducted in the DTNSRDC 8- by 10-foot north subsonic wind tunnel. The model was floor mounted in a vertical position using Strut System 8. Blowing air was supplied through a pipe in the center of this strut. The strut system is located beneath the tunnel floor and transfers the aerodynamic loads to an external Toledo mechanical balance system. The Toledo balance system records six-component force and moment data on magnetic tape using a Beckman 210 high speed data acquisition system.

Three total pressure transducers and one thermocouple temperature probe were mounted in the wing plenum. Due to the difficulty of actually measuring the jet velocity, it was calculated assuming isentropic expansion of the air from the total pressure in the wing plenum to free-stream static pressure. The jet velocity can be determined from the expression (Reference 2):

$$V_j = \sqrt{\frac{2\gamma RT_d}{\gamma - 1} \cdot \left[1 - \left(\frac{P_\infty}{P_d}\right)^{\frac{\gamma-1}{\gamma}}\right]}$$

The mass flow of the jet $\dot{m}$ was measured by a venturimeter in the air supply line. The blowing coefficient C_μ is determined from the expression:

$$C_\mu = \frac{\dot{m}V_j}{qS}$$

For each configuration, the model was set at an angle of attack and data was taken at different blowing coefficients by varying the plenum pressure. The model was then set at the next angle of attack, and the process was repeated.

All forces and moments were resolved about the mean aerodynamic chord and reduced to standard coefficient form using the stability axis system. Coefficients were based on twice the reference area of the semi-span model to simulate the case of a full-span model. Net rolling and

yawing moments (ΔC_ℓ and ΔC_n) are the differences between the moment coefficients with and without blowing.

Each data point was taken as the average of 10 data samplings over a 5-sec interval. Model weight and air pressure line tare corrections were applied to the balance data. The only aerodynamic corrections applied to the force and moment data consisted of the standard downwash corrections as outlined in Reference 3; angle of attack and drag coefficient were the two parameters affected.

All data were recorded at a dynamic pressure of 20 lb/ft^2 (957 N/m^2) with a Reynolds number of 0.8×10^6 (2.62×10^6/m). The 20- and 10-percent CC ailerons were each tested at five momentum coefficients. Angle of attack was varied from 0 to 24 deg in 4-deg increments.

RESULTS AND DISCUSSION

The rolling moment coefficient about the centerline of the half model for the configurations evaluated is shown in Figures 6a through 6f. The application of roll control to lift one wing is modeled as blowing on one CC aileron and no blowing on the other. The net rolling moment that would be felt by a whole model with a certain amount of blowing on one CC aileron is the difference between that blown curve and the unblown curve.

The four 20-percent CC ailerons show a net rolling moment that is fairly even with angle of attack for each momentum coefficient. A much smaller net rolling moment was generated by the two 10-percent CC ailerons with blowing. Scatter in the data is probably responsible for most of the unevenness of the increments.

Figures 7a through 7f show net rolling moment versus momentum coefficient for all six configurations evaluated. Lines fanning out from the origin represent levels of constant rolling moment enhancement. Rolling moment enhancement is the net rolling moment achieved with the device divided by the net rolling moment that would be produced by using the air for a tip jet (assuming no losses in the tip jet).

$$\text{Enhancement} = \frac{\Delta C_{\ell} qSb}{\dot{m}V_j(b/2)}$$

$$= \frac{\Delta C_{\ell} qSb}{C_{\mu} qS(b/2)}$$

$$= \frac{2\Delta C_{\ell}}{C_{\mu}}$$

For the 20-percent CC aileron, net rolling moment increases nonlinearly with momentum coefficient, with less incremental net rolling moment being gained by additional blowing. At the maximum momentum coefficient tested, the device was still showing increasing net rolling moment with increasing blowing. A rolling moment enhancement greater than four was achieved by the 20-percent CC ailerons in most conditions, and enhancement greater than 12 was achieved by the short edge configuration at low momentum coefficients.

The rounded edge and square edge configurations performed better than the long edge configuration with a maximum net rolling moment of 0.037 compared to 0.030. Removing the fence from the round edge configuration decreased maximum net rolling moment by 10 percent, from 0.037 to 0.033. The fence increased the performance of the low aspect ratio blown section by making it more like a two-dimensional section. The 10-percent CC ailerons showed similar nonlinear trends with momentum coefficient, but performance was only one-third as good as the 20-percent CC ailerons. The comparatively poor performance of the 10-percent CC aileron is probably due to the very low aspect ratio of the blown portion of the wing. Again, the square edge configuration performed better than the long edge configuration.

Adverse yaw plots for the 20-percent square edge and long edge configurations are shown in Figures 8a and b. The adverse yawing moments measured were large, on the order of one-half of the rolling moment. The square edge configuration shows increasing adverse yaw with angle of attack with the exception of zero angle of attack.

SUMMARY AND CONCLUSIONS

A CC aileron was evaluated in a low-speed wind tunnel test for potential use on V/STOL aircraft. A large amount of roll power for a small expense of bleed air was desired. (The highest rolling moment achieved was $C_\ell = 0.037$ for a momentum coefficient of $C_\mu = 0.014$, which represents a rolling moment enhancement of 5.29. The adverse yawing moment measured was approximately one-half of the rolling moment.) The 20-percent CC aileron performed three times as well as the 10-percent CC aileron. A fence on the inboard edge of the CC aileron increased performance. The rounded edge and square edge configurations performed better than the long edge configuration.

Various improvements are recommended for further investigation. A spoiler raised on the opposite wing would increase rolling moment and reduce adverse yaw by increasing drag on that wing. Up blowing on the opposite wing from a slot on the underside of the trailing edge would also increase rolling moment, but its effect on adverse yaw is uncertain.

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3. Pope, A. and J.J. Harper, "Low Speed Wind Tunnel Testing," John Wiley & Sons, Inc., New York (1966).

NOMINAL ASPECT RATIO	CHORD		SWEEP (deg)		
	TIP	ROOT	L.E.	T.E.	SEMISPAN
3	8.40 in. (21.34cm)	18.34 in. (46.58cm)	25.8	0	1.91 ft (0.582m)
4	6.42 in. (16.31cm)	18.34 in. (46.58cm)	25.8	0	2.12 ft (0.646m)

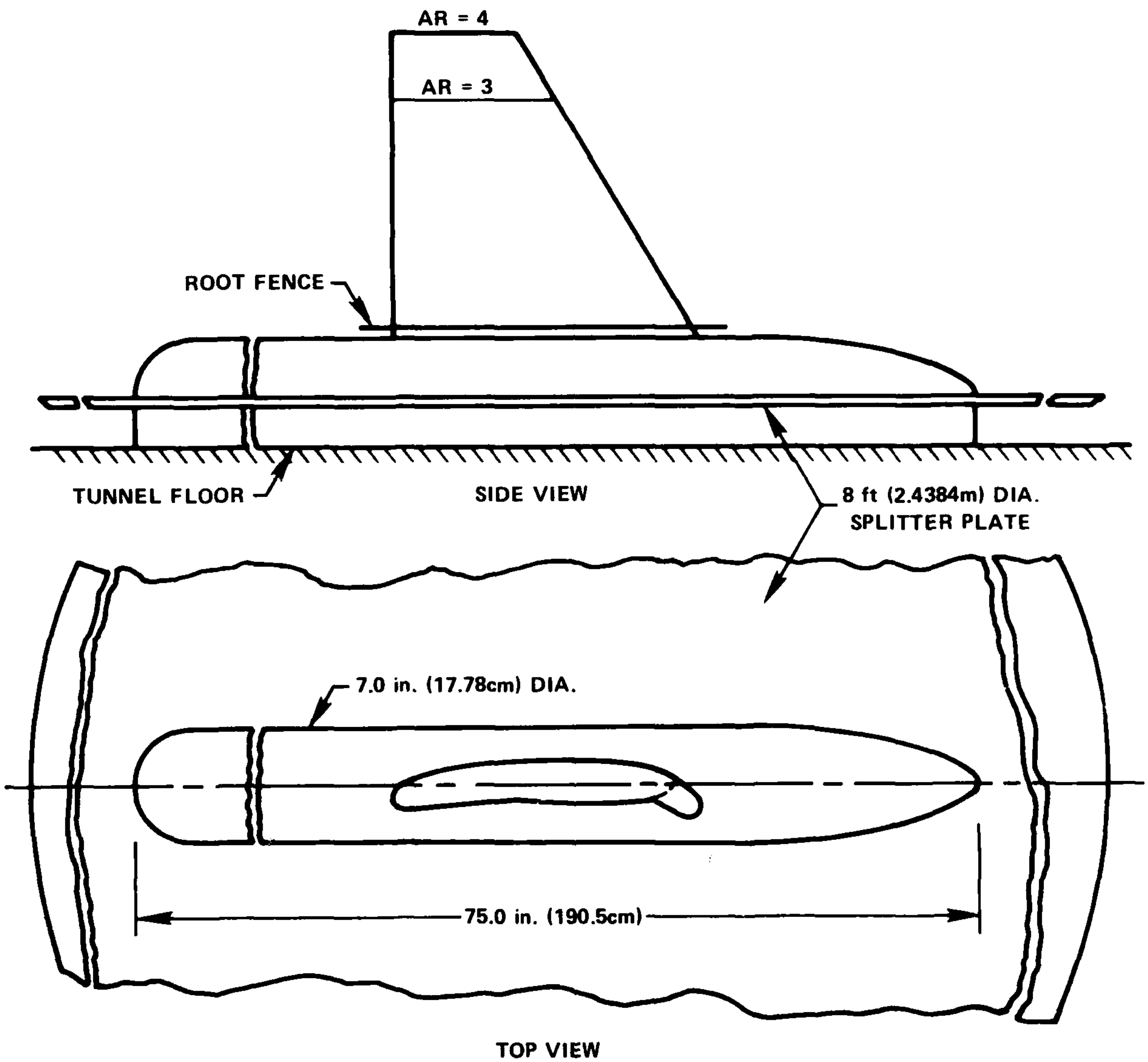


Figure 1 - Semispan Wing - Fuselage Model and Ground Board

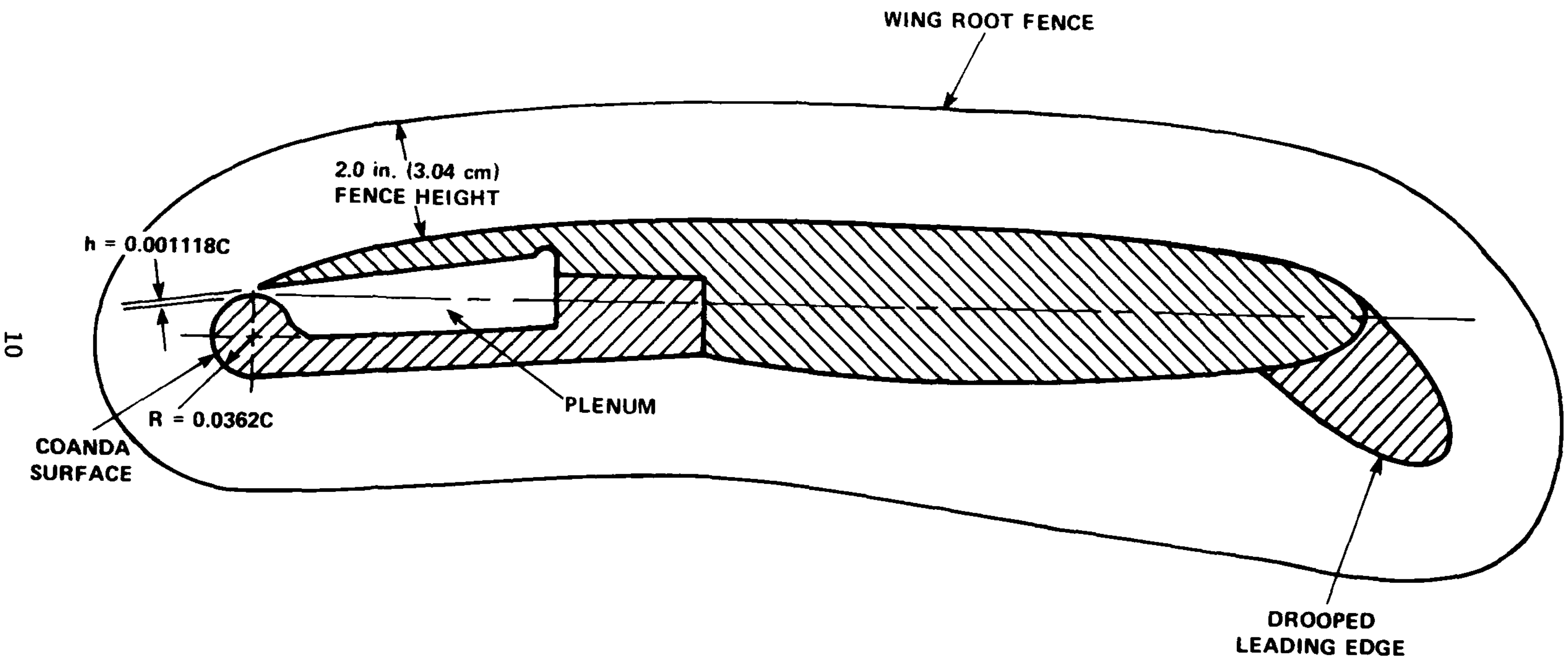
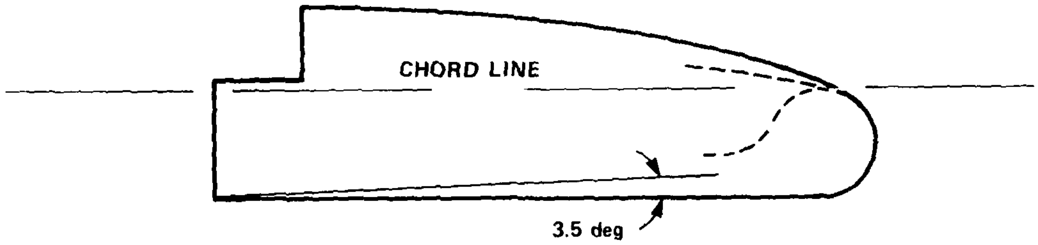
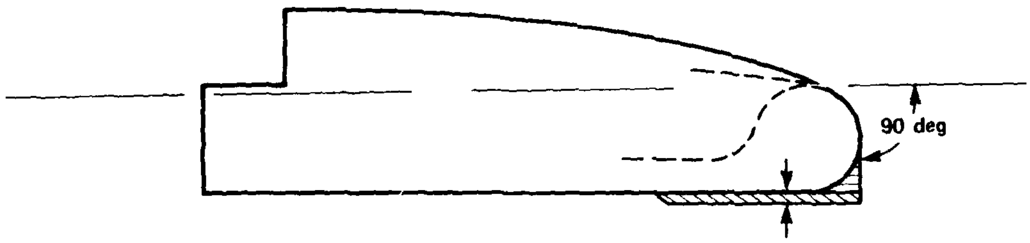


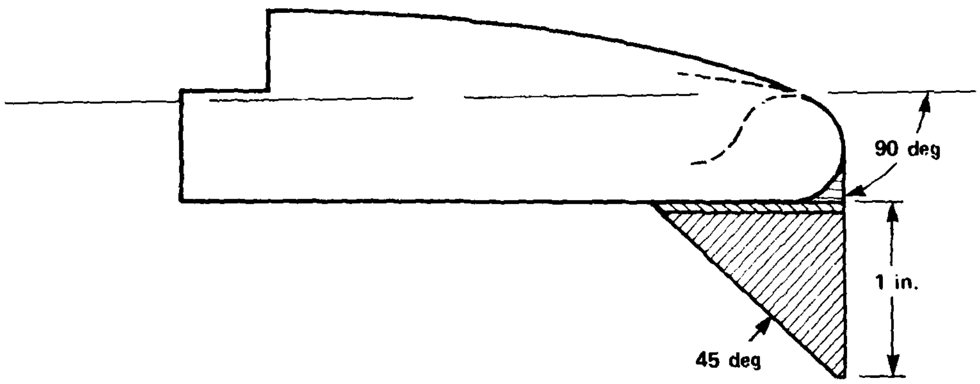
Figure 2 - Fourteen-Percent Supercritical Airfoil with Circulation Control Trailing Edge



CIRCULATION CONTROL AILERON



CIRCULATION CONTROL AILERON WITH SIMULATED SHORT FLAP



CIRCULATION CONTROL AILERON WITH SIMULATED EXTENDED FLAP

Figure 3 - Geometry of Circulation Control Aileron
Trailing Edge Configurations

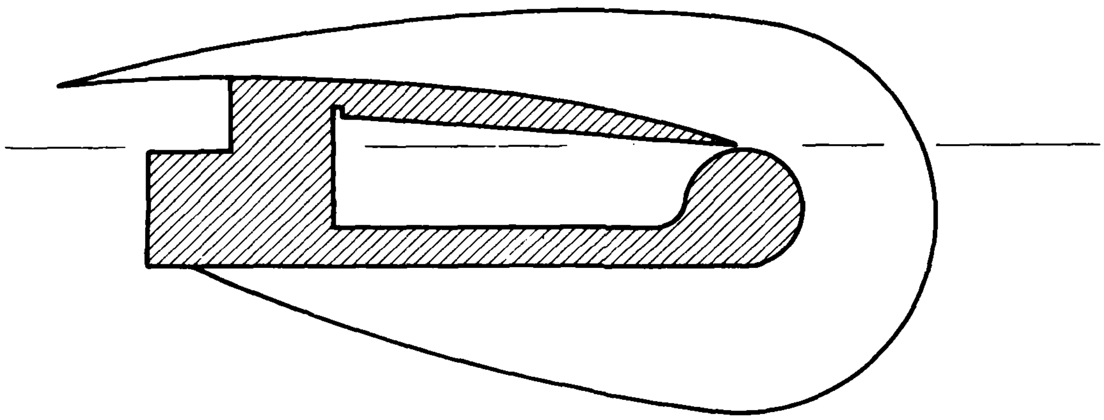


Figure 4 - Wing Fence Inboard of Circulation Control Aileron Section

Figure 5 - Semispan Circulation Control Wing-Fuselage Model

Figure 6 - Rolling Moment Coefficient versus Angle of Attack

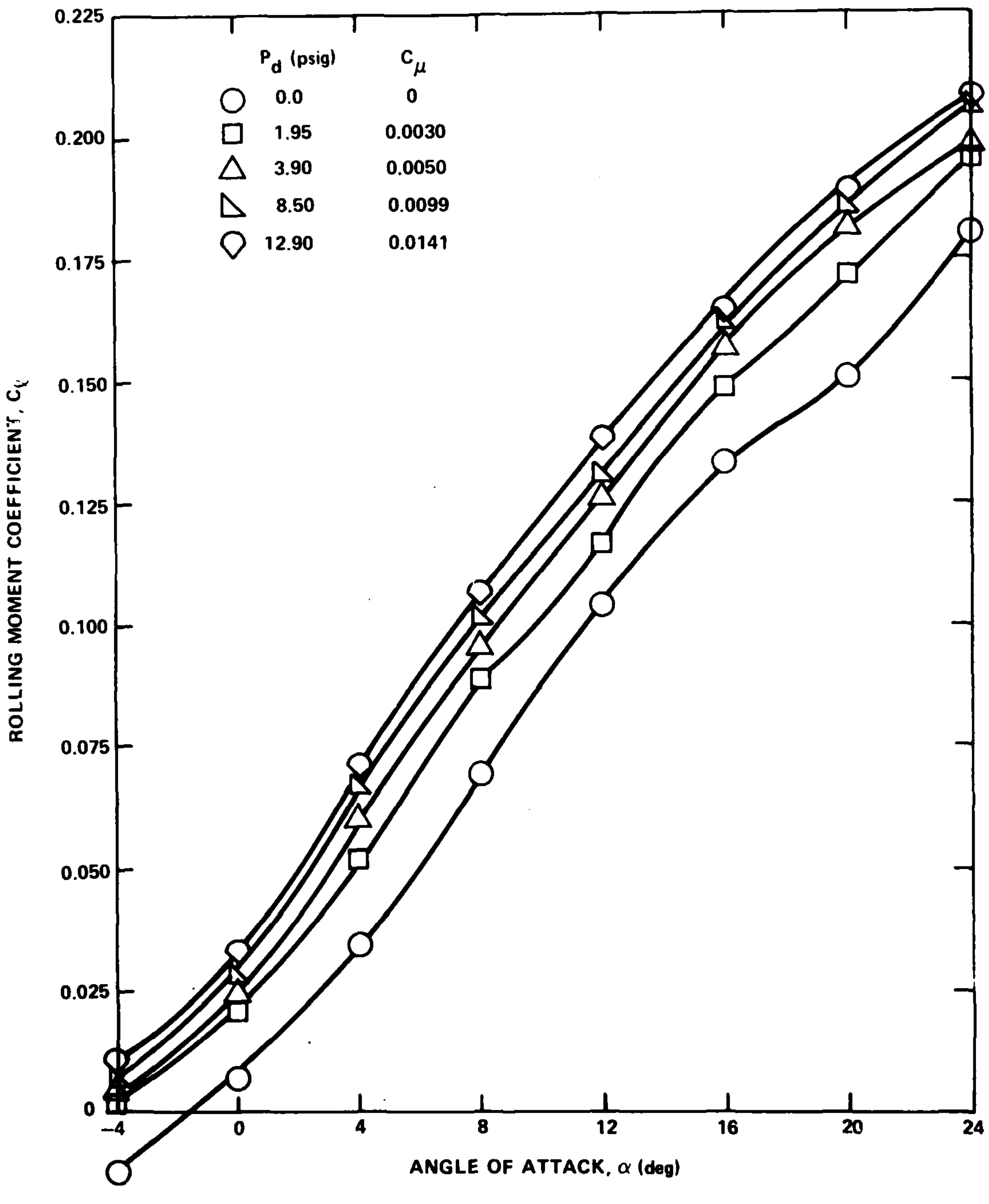


Figure 6a - Twenty-Percent CC Aileron, Simulated Short Flap

Figure 6 (Continued)

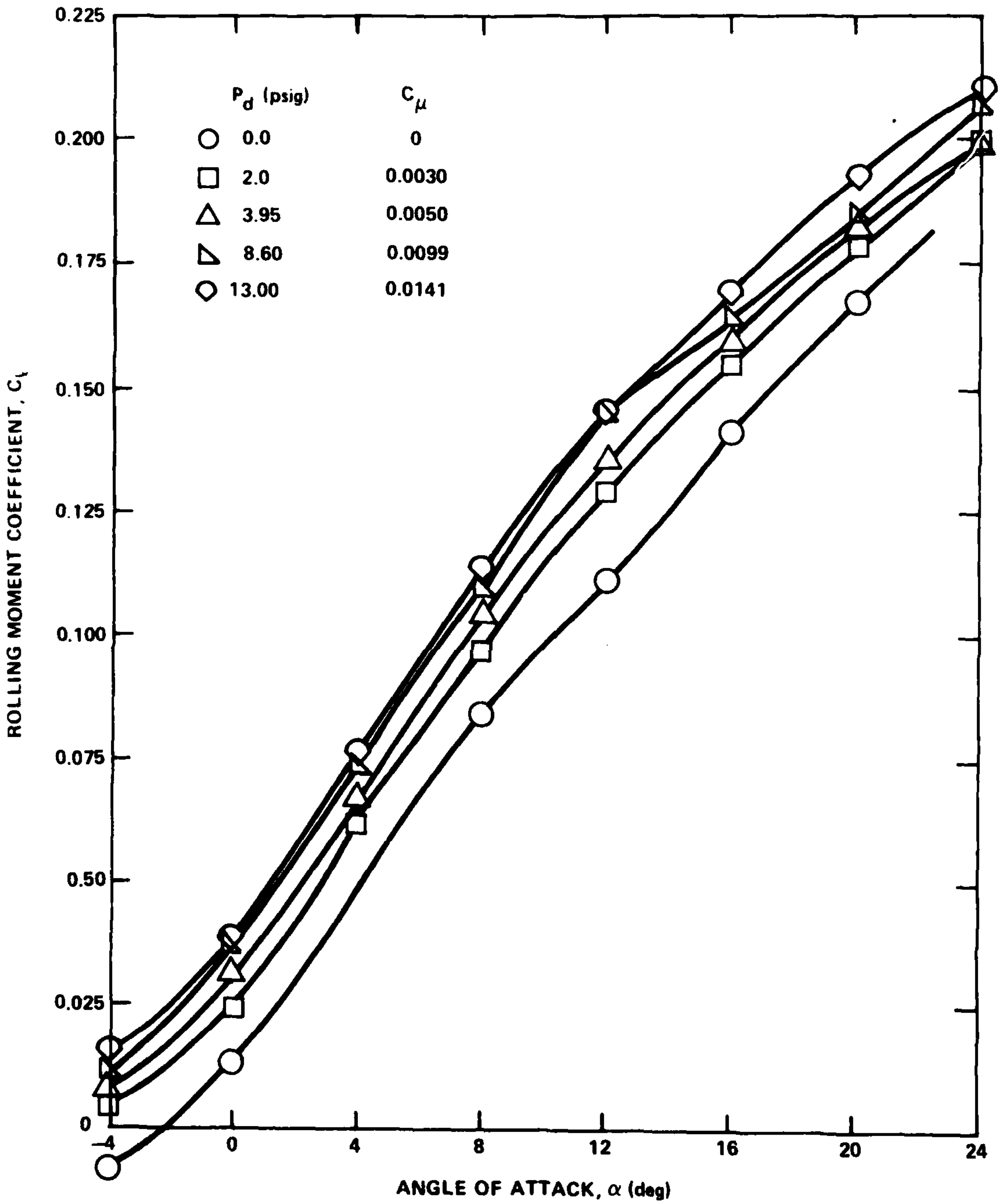


Figure 6b - Twenty-Percent CC Aileron, Simulated Extended Flap

Figure 6 (Continued)

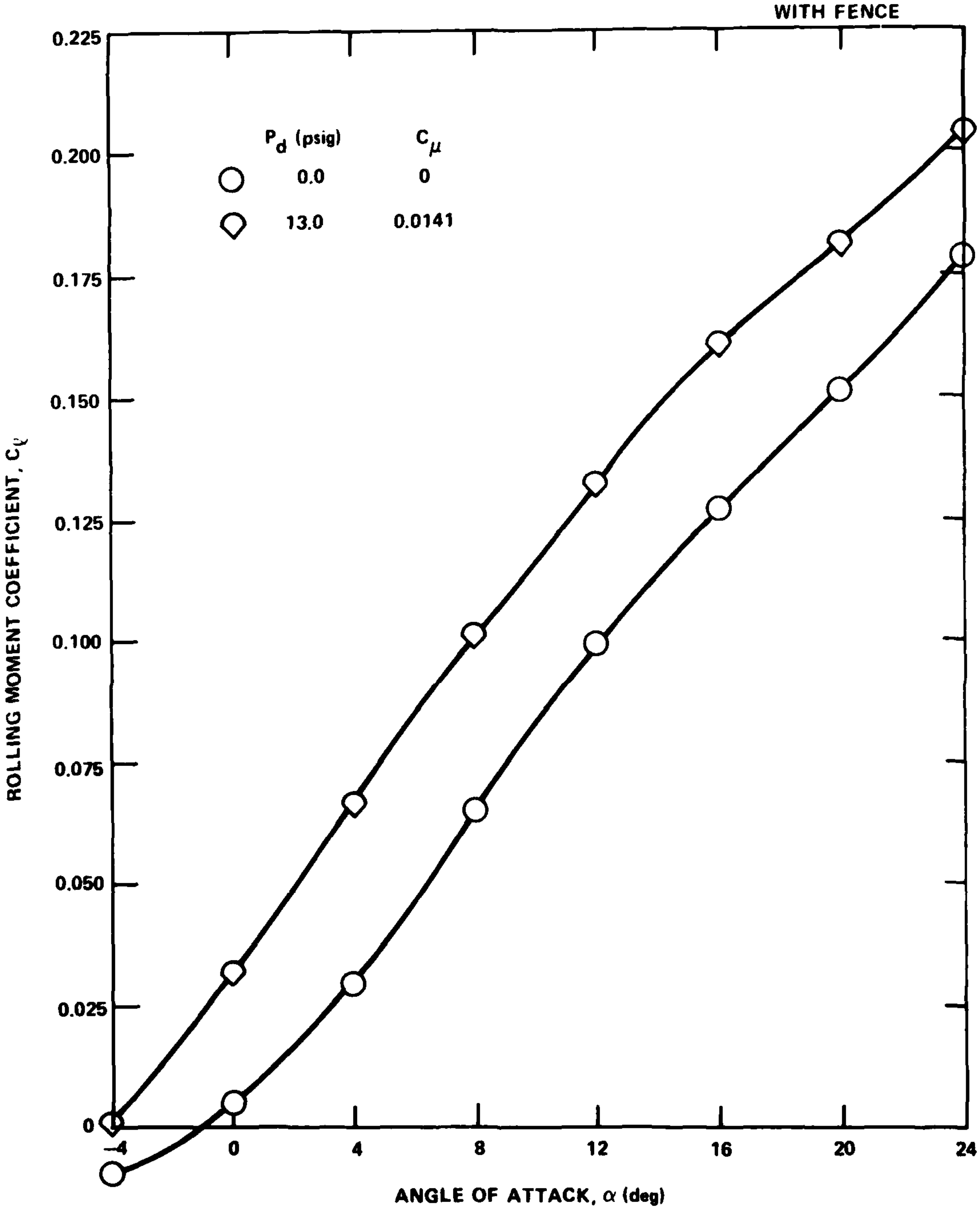


Figure 6c - Twenty-Percent CC Aileron, with Fence

Figure 6 (Continued)

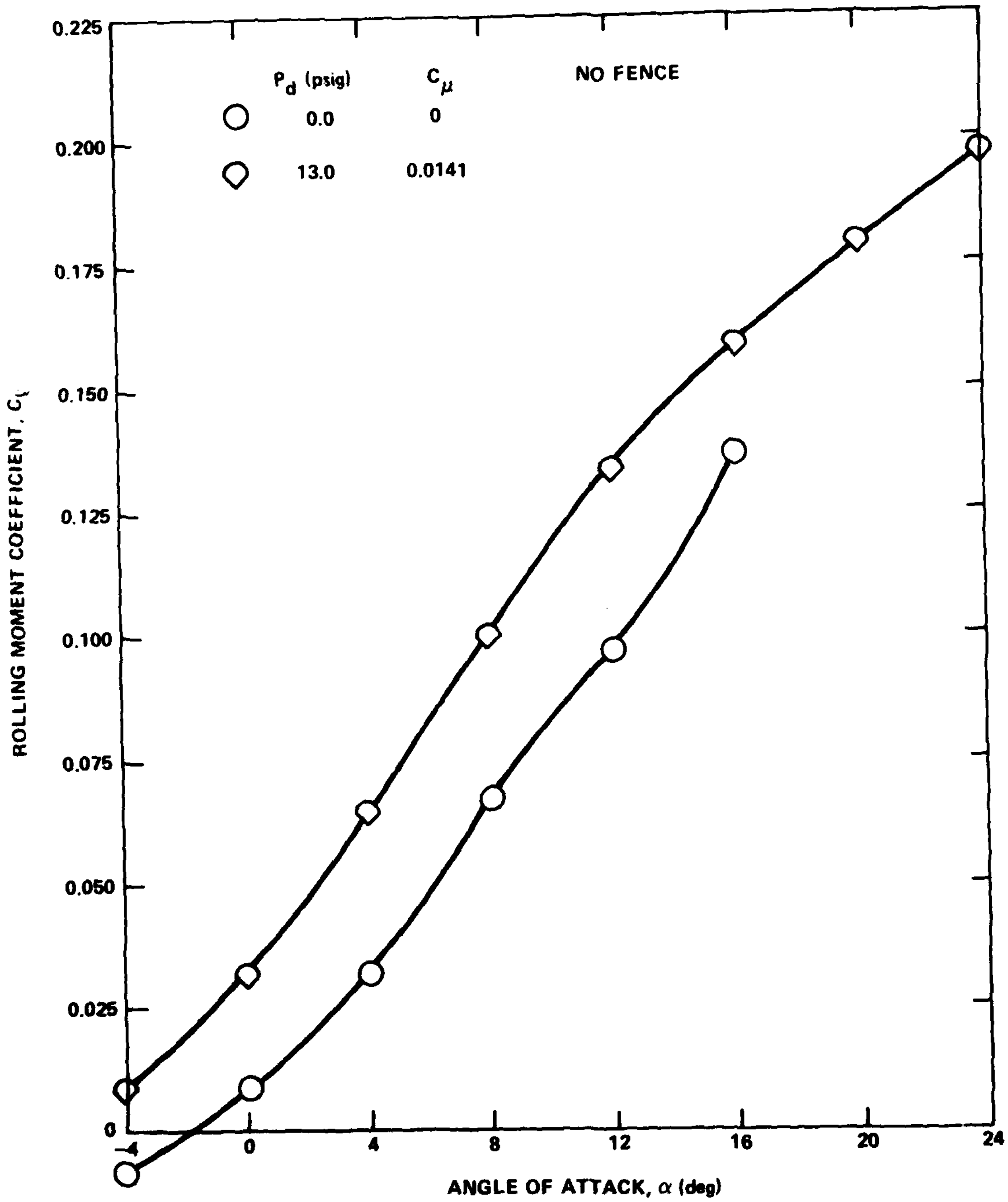


Figure 6d - Twenty-Percent CC Aileron, without Fence

Figure 6 (Continued)

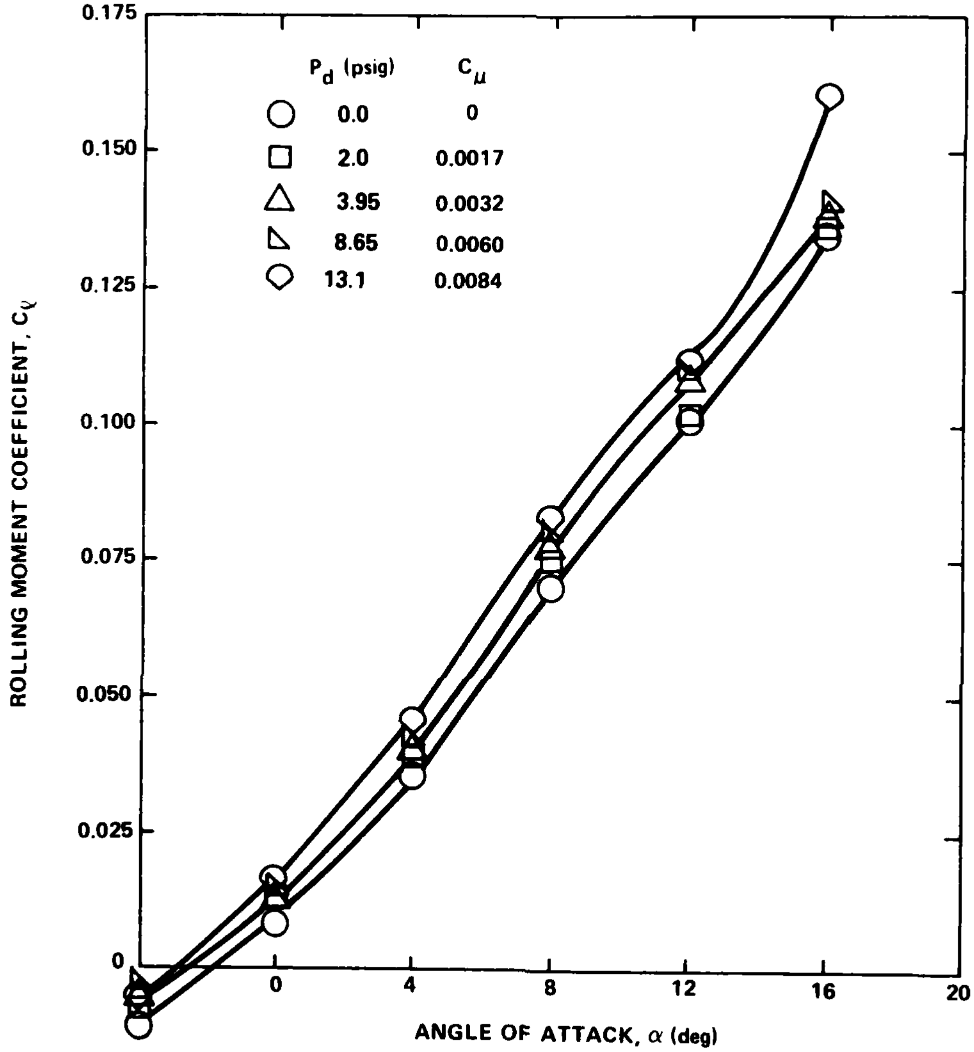


Figure 6e - Ten-Percent CC Aileron, Simulated Short Flap

Figure 6 (Continued)

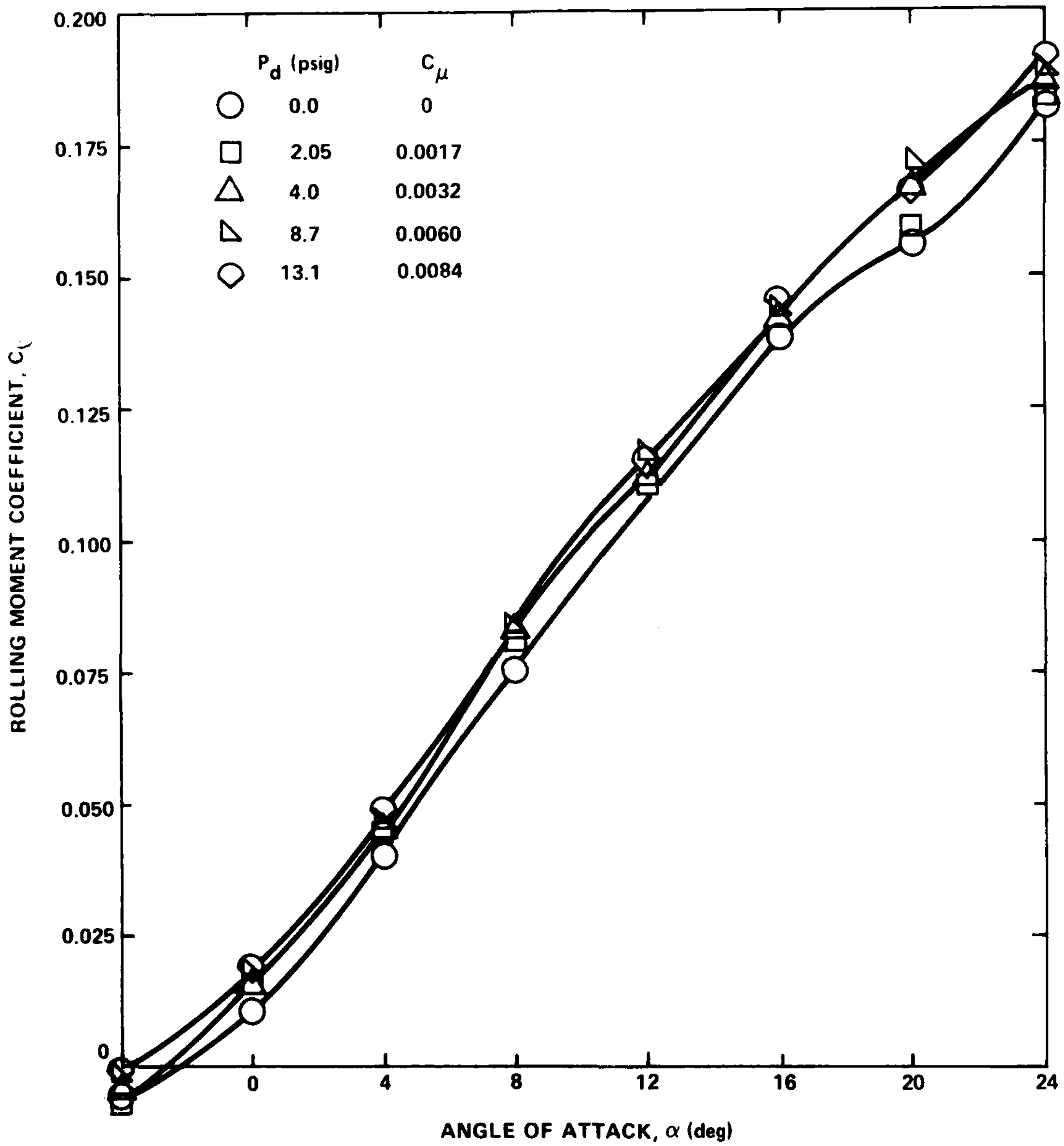


Figure 6f - Ten-Percent CC Aileron, Simulated Extended Flap

Figure 7 - Rolling Moment Enhancement

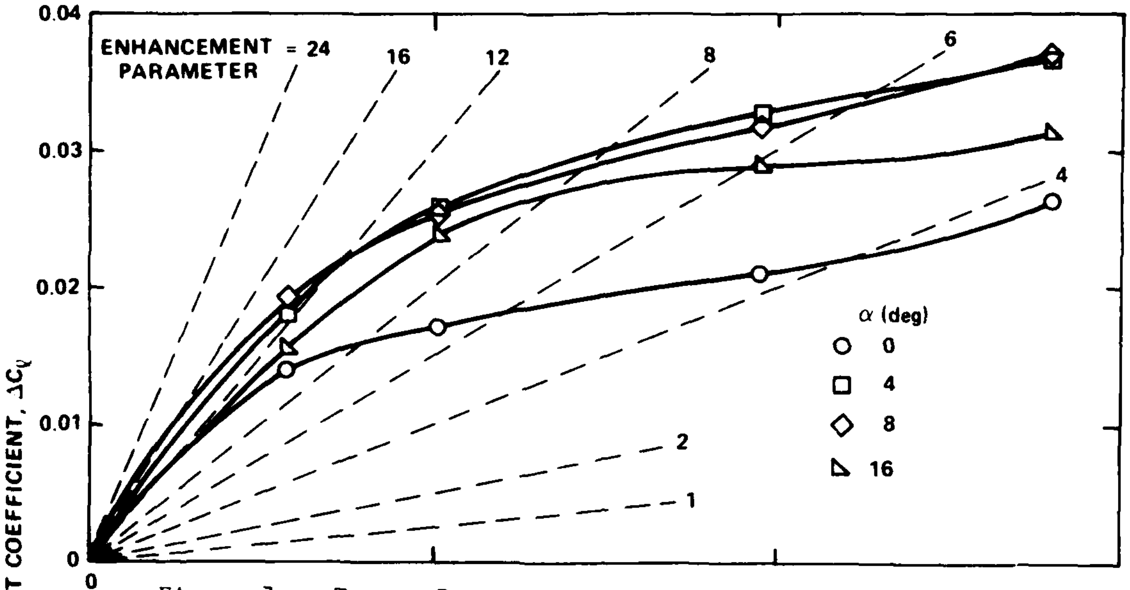


Figure 7a - Twenty-Percent CC Aileron, Simulated Short Flap

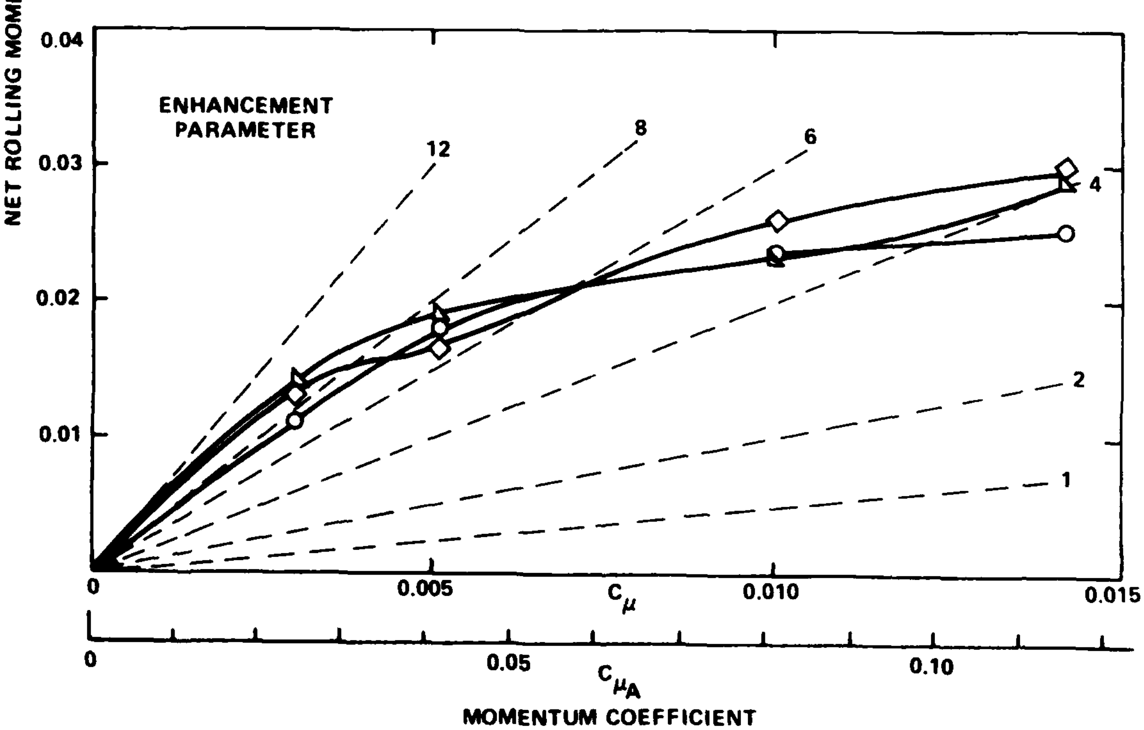


Figure 7b - Twenty-Percent CC Aileron, Simulated Extended Flap

Figure 7 (Continued)

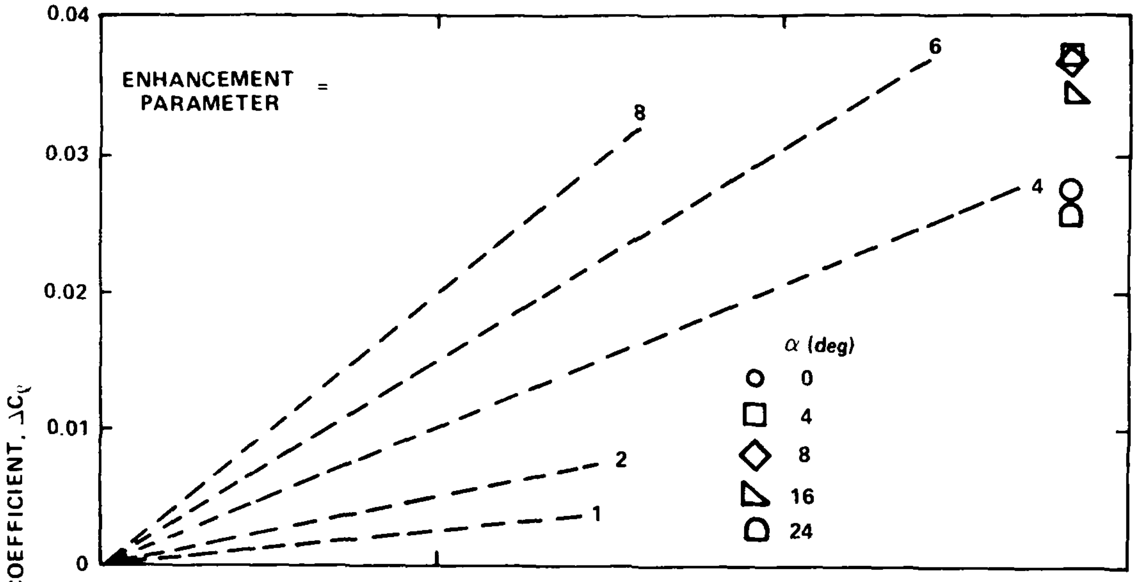


Figure 7c - Twenty-Percent CC Aileron, with Fence

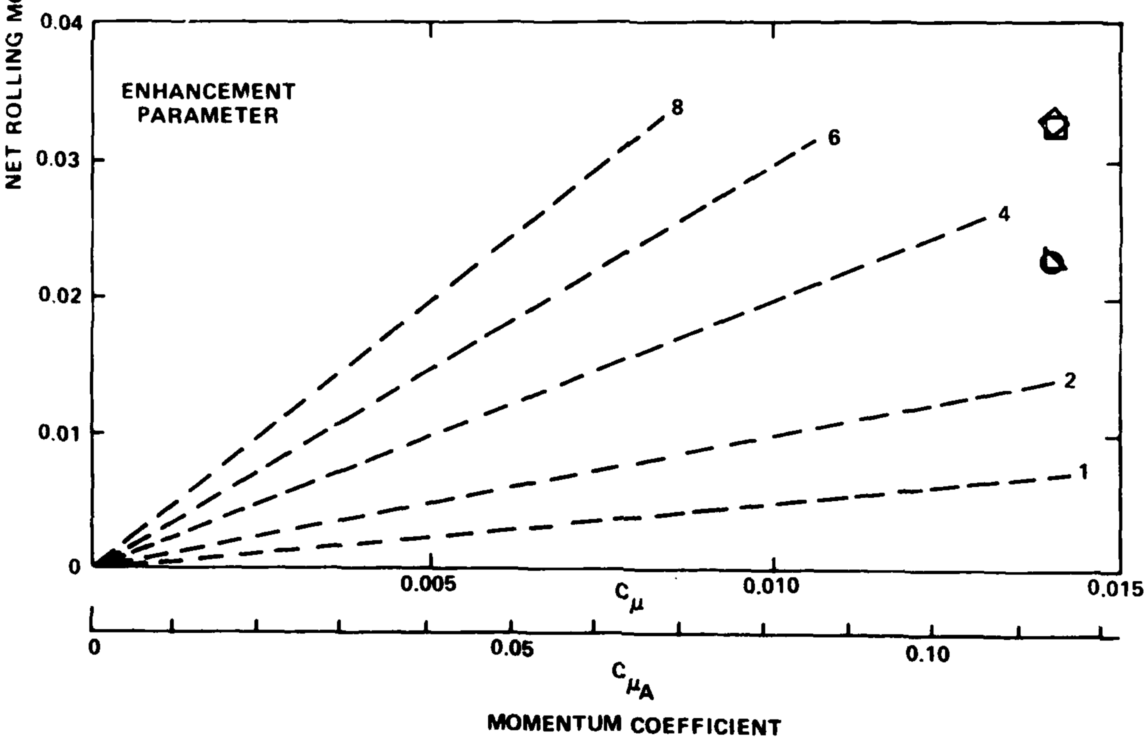


Figure 7d - Twenty-Percent CC Aileron, without Fence

Figure 7 (Continued)

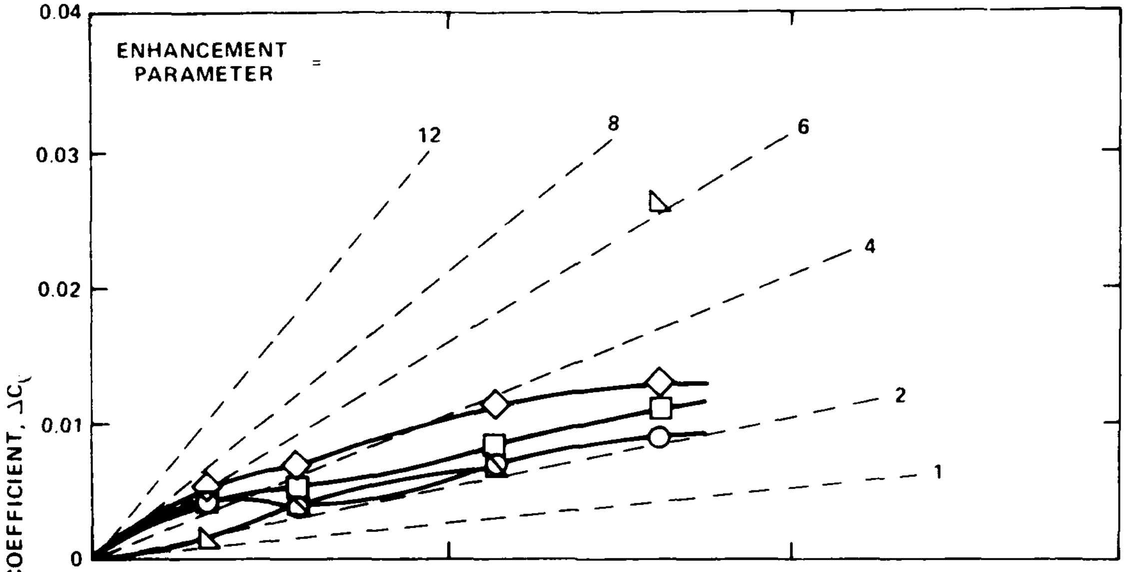


Figure 7e - Ten-Percent CC Aileron, Simulated Short Flap

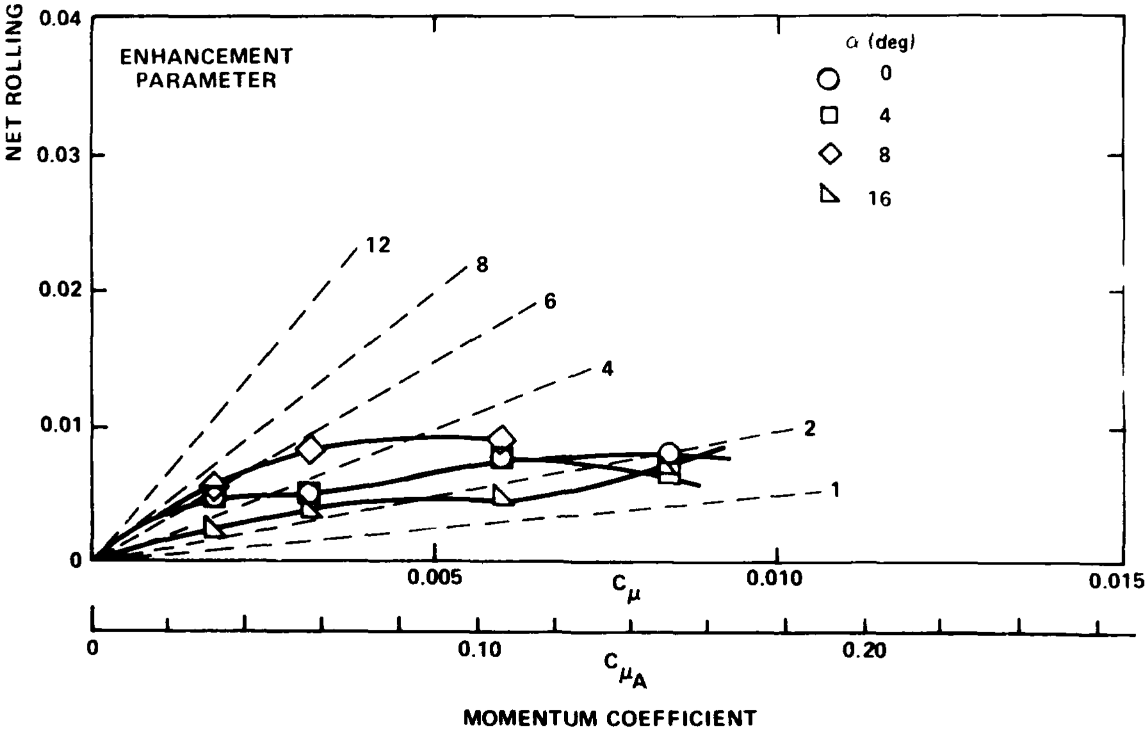


Figure 7f - Ten-Percent CC Aileron--Simulated Extended Flap

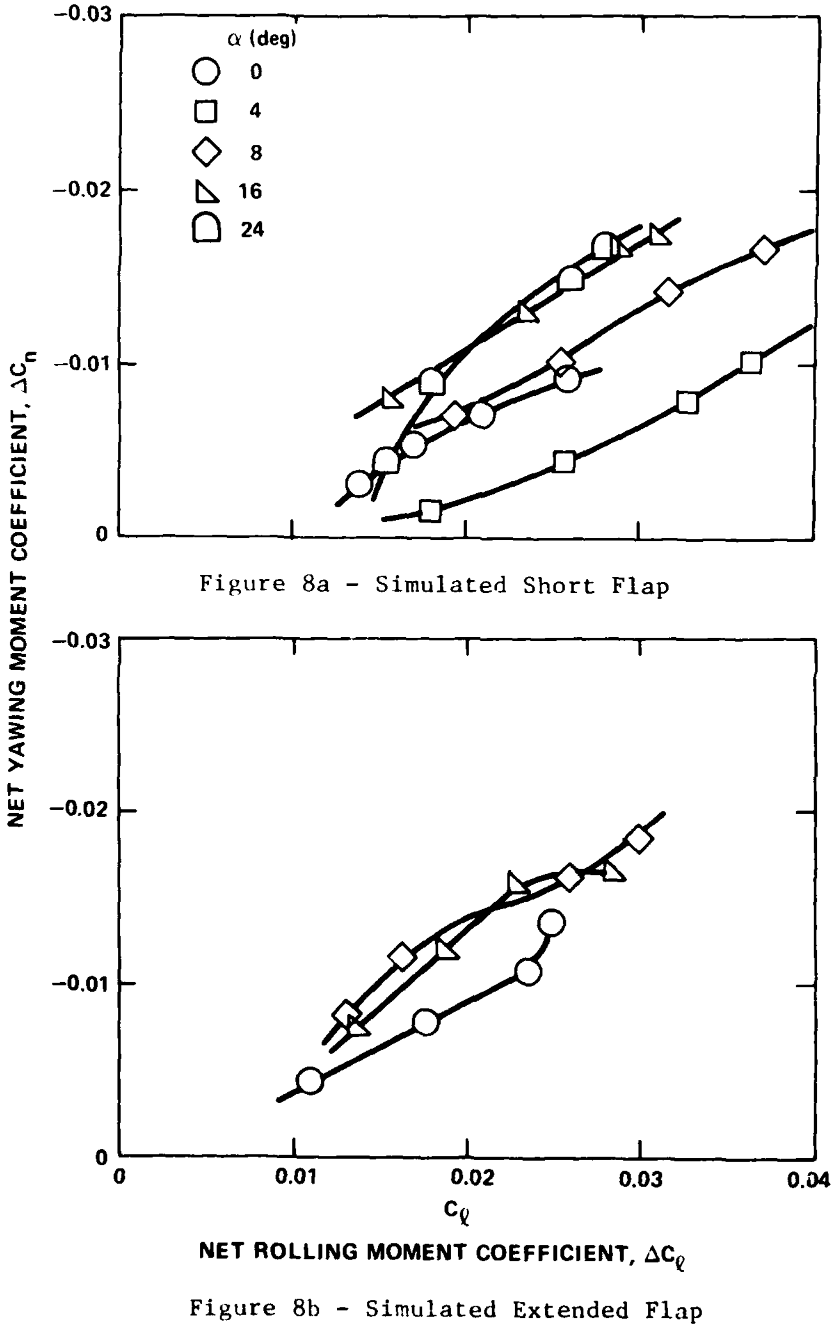


Figure 8a - Simulated Short Flap

Figure 8b - Simulated Extended Flap

Figure 8 - Adverse Yawing Moment of the Twenty Percent Circulation Control Ailerons

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